LCA Methodology

Evaluation of Life Cycle Impacts: Identification of Societal Weights of Environmental Issues

Shirish Sangle[1], P. Ram Babu[2], P. Khanna[3]

[1]National Environmental Engineering Research Institute, Nehru Marg Nagpur, India; e-mail: shirish_sangle@hotmail.com
[2]National Environmental Engineering Research Institute, Nehru Marg Nagpur, India; e-mail: prambabu56@hotmail.com
[3]National Environmental Engineering Research Institute, Nehru Marg Nagpur, India

Corresponding author: Dr. P. Ram Babu

Abstract

A new method for identification of weights of environmental issues is suggested using the societal approach in the context of a weighting step in Life Cycle Assessment (LCA). The weights assigned by different economic groups to eleven environmental issues is obtained through analysis of linguistically stated relative rankings using a fuzzy partial ordering method. The system identification technique based on neural networks is used to identify logical connective in the stated relative rankings and this obviated the inconsistency problem normally encountered in the analysis of relative preference statements. The transitive property of a matrix of relative weights is used to minimise the number of responses to be elicited from a respondent.

Keywords: Environmental issues; fuzzy partial ordering; Life Cycle Assessment; Life Cycle Impact Assessment; neural networks; relative ranking; societal weights; weighting

1 Introduction

Life cycle assessment (LCA) is an analytical tool that evaluates the environmental consequences of a product, process or service throughout its life cycle, viz. from cradle to grave. Environmental LCA can be viewed as part of a more comprehensive assessment of a product including environmental impacts, consumer safety, cost and other aspects [1].

Unlike the goal definition and inventory analysis, the weighting step in Life Cycle Assessment is not well formulated. The weighting step involves an identification of trade-offs amongst multiple environmental consequences identified through the inventory analysis and characterisation. The ranking (comparison) of environmental issues and assignment of weights are critical as product alternatives and may contribute less to one environmental issue and more to others. The basic problem of decision making under such situations is to rank competing alternatives using multiple criteria. The following methods, besides a societal approach, are commonly used for weighting in Life Cycle Assessment [2]:

- monetary methods
- sustainability levels
- modelling of the eventual effects

The monetary methods based on avoidance/prevention/damage costs form the basis of a relative comparison between the environmental issues [3] and may bear no relation to the extent of degradation caused by the use of emissions or resources. The contingent valuation method, and other in-vogue monetary valuation methods, do not consider the spatio-temporal distribution of avoidance, or damage costs and 'societal preferences'. Sustainability levels are a long-term compromise between desirability and techno-economic feasibility. Levels of sustainability, which are based on bio-geo-physico-chemical considerations, are no doubt the best, but are difficult to estimate. The methods of valuation through modelling of eventual effects are more complex than defining scientifically sound levels of sustainability.

The societal weighting approach presupposes that weighting in life cycle assessment is normative [4] and the relative importance of environmental issues is subjective in nature. Hence, the weighting of environmental issues would have to take into consideration the preferences, aspirations, and values of citizens, based on which appropriate measures could be taken to meet their expectations. In addition, such an approach is also consistent with confirming to customers' explicit and implicit expectations as required by Total Quality Environmental Management.

2 Societal Weighting

The challenge in weighting is to assign weights to environmental issues characterised by different units. The preferences or weighting factors of environmental issues can be obtained directly from citizens viz. *stated preferences* [2] or can be reconstructed on the basis of recent policy statements, i.e. *revealed preferences*. The elicitation of direct ranking of these issues is infeasible and may lead to erroneous results. The direct ranking is only feasible when absolute measurements are available and when comparisons are made amongst homogenous objects viz. problems of comparable size and similar nature. For absolute measurement one needs standards, often set by society for convenience, and sometimes has little to do with values and objectives of a judge making comparisons. In a decision-making situation where no standards are available, one must use relative measurements to

rank issues by comparing them in pairs. The weighting using relative ranking of environmental issues is more reliable, although the number of comparisons would be large.

The weights can also be derived through an analysis of revealed preferences. However, it is complex to obtain a reliable estimation of societal weights through the analysis of explicit expressions such as policies, budget allocations and other related articulations and implicit expressions such as transactions in the market. The stated preferences have an advantage, in addition, that these are likely to reflect the societal aspirations and also that variations across the economic sections of the society can be ascertained. Categorisation of relative ranking across the economic sections of the society would be useful as significant impacts of different life cycle stages would effect different sections of the society.

In the weighting step, through societal approach for identification of weights for environmental issues, the regional specificity in LCA can be incorporated [5] as any individual or group of individuals would have a definite concern for local, regional and global level problems. In principle, the societal weighting must incorporate responses of all the stakeholders of environment in the region under consideration. The societal weighting method is first used by Mckinsey and Company [6], further developed by Heijungs et al. [2] as well as Kortman et al. [7]. Kortman et al. and Heijungs et al. [8] conclude that the structure of questions are critical in determination of the relative ranking. Heijungs, R. [9] proposes a societal weighting approach considering stated preferences for determination of weighting factors, although the following issues are not satisfactorily addressed in the above investigation:

- ranking of environmental issues characterised by different units
- ranking procedure
- identification of weights of environmental issues.

Heijungs [9] elicits the preferences from respondents directly in terms of numerical percentages. Such an elicitation in terms of numerical value may be acceptable in the case of contingent valuation studies where the respondent values only one resource or environmental issue. In addition, percentages in contingent valuation may provide a tangible reference situation, but a comparison of environmental issues in terms of percentages is difficult. For example, it is very difficult to assess a 1% increase in the contamination of river water from its current level (tangible reference). It is also not clear as to what meaning this number '1% increase' may convey, or what significance this percent increase in surface water contamination has. Often, LCA is performed by industry to gauge and conform to environmental preferences of citizens or stakeholders irrespective of their willingness-to-pay towards protection of natural resources, reduction of pollution or disturbances to ecosystems. In addition, the in-vogue societal approaches do not differentiate between different sections of the society. This, as argued earlier, would be useful in assessing the severity of environmental impacts in different stages of a life cycle to different sections of society.

Analytical Hierarchy Process (AHP) [10 - 13] and other similar multi-criteria decision-making methods [14 - 18] provide a comprehensive framework for deriving weights through an analysis of elicited relative weights/rankings. The AHP and other such methods suffers from the following defects:

- a large number of relative preferences to be elicited viz. to compare n objects, one requires n(n-1)/2 pair-wise comparisons
- the problem of inconsistency amongst elicited relative weights
- the system may not obey hierarchy.

This study delineates a new method of identification of societal weighting of environmental issues in the context of LCA and illustrates it through a survey in the National Capital Region (NCR) of India. Our methodology for weighting environmental issues by societal approach is outlined in Section 3. The illustration of this methodology is discussed in Section 4 by taking the case of NCR in India. The conclusions are presented in Section 5.

3 Weighting Methodology for Evaluation of Life Cycle Impacts

The proposed method of identification of societal weights involves five steps:

- Identification of environmental issues
- Elicitation of pair-wise relative rankings
- Identification of logical connection operator in the matrix of relative weights
- Constitution of the matrix of relative weights
- Deduction of weights of environmental issues.

The five-step procedure delineated and illustrated in this study has the following advantages:

- Simpler than the indirect methods of revealed preferences
- More reliable than the direct elicitation of weights or rankings
- Avoids inconsistency problems and reduces number of responses to be elicited

3.1 Identification of environmental issues

The environmental issues are identified through revealed preferences viz., content analysis of national and federal policy documents, statements of opinion makers, public participation records and other reports related to the environmental issues. However, it is important in the identification of environmental issues that these be defined as much as possible at comparable levels of environmental mechanisms (ISO terminology for cause-effect networks) of the categories. This is to avoid possible overlap amongst categories.

3.2 Elicitation of pair-wise relative weights

It is important to identify all the stakeholder groups involved in the different life cycle stages of the product or service. A representative sample of individuals amongst all stakeholder groups are chosen for the elicitation of pair-wise relative weights of two environmental issues against a set of criteria in linguistic terms.

Non-specificity / ambiguity is inherent in all the elicitation methods, and to a large extent is arbitrarily avoided by the decision analyst [19]. In several methods for solving multi-

criteria decision-making problems, viz. Analytical Hierarchical Process (AHP), Multi Criteria Analysis (MCA), Multi Attribute Utility Theory (MAUT), and Impact Analysis Matrix (IAM), the non-specific statements are converted to crisp-scaled discrete scores arbitrarily. This, besides other reasons, causes an inconsistency in the set of relative weights which is normally solved by iterative matrix algebraic techniques.

The ambiguity/non-specificity in stated preferences is due to unfamiliarity with the elicitation process, incomplete information or knowledge, and incomplete comprehension of the underlying system. Thus, it is important to seek appropriate representation of the ambiguity/non-specificity associated with elicited responses using fuzzy numbers [20]. It is amply demonstrated in the literature that triangular fuzzy numbers (TFN) are adequate to represent the non-specificity in many contexts. In this study, the pair-wise comparison of two environmental issues elicited in the form of linguistic variables is represented as a symmetric triangular fuzzy number. This representation rendering simplicity and further generalisation is straightforward. The shape of triangular fuzzy numbers[1] [21] is chosen to be consistent with the fact that extreme judgements have lower levels of non-specificity.

3.3 Identification of logical connection operator in matrix of relative weights

To obtain relative weights of **n** environmental issues, elicitation of **n(n-1)** pair-wise comparisons are to be elicited. The elements of matrix of relative weights X_{ij} – magnitude of preference to the i[th] environmental issue over j[th] – possess the following properties:

- reflexive ($X_{ij} = 1$ if $i = j$)
- anti-symmetric ($X_{ij} \otimes X_{ji} = 1$)
- transitive ($X_{ij} \otimes X_{jk} = X_{ik}$)

The properties of *antisymmetry* and *transitivity* of matrix of relative weights can be used to reduce the number of relative weights without introducing inconsistency only if the logical connective (⊗) is identified. In decision sciences, commonly used logical operators are 'addition' (OR) and 'multiplication' (AND) and, in certain situations, a linear or nonlinear combination of these operators is also used. The concomitant inconsistency in the matrix of relative weights is surmounted through iterative matrix algebraic procedures [22]. The critical issue of identifying the logical connection operator to avoid inconsistencies is not addressed in the literature.

In the present study, neural networks and fuzzy aggregation methods are explored for an identification of logical connection operator and neural networks are found to be more effective than the fuzzy aggregation operators for this task. The neural network[2] model for identification of logical connection is delineated below:

- The training and test patterns are formed out of elicited chained relative weights, e.g. X_{ij}, X_{jk}, and X_{ik} constitute one pattern
- Element of the matrix of relative weights - a triangular fuzzy number X_{ij}, = X^1_{ij}, X^2_{ij}, X^3_{ij}, is reduced to a diad
- Out of the four input neurons I1, I2, I3 and I4, I1and I2 represent the elements of the diad reflecting the relative weights of environmental issues i over j, and similarly, I3 and I4 represent the relative weightage of environmental issue j over k
- The two output neurons represent elements of the diad representing a preference between environmental issues i and k
- Back propagation algorithm, sigmoidal function based firing mechanism, control parameters such as the number of hidden layers and learning rate characterise a neural network model
- The training of a network involves more than 150,000 iterations
- The verification of the forecasts against the test patterns are used to validate whether the neural network identified a desired logical operator or not
- The trained and tested neural network represents the logical connection operator.

3.4 Constitution of matrix of relative weights

Using the identified logical connection operator, and the reflexive, anti-symmetric, and transitive properties, the matrix of relative weights can be generated with a comparatively fewer number of elicited relative weights. The matrix of relative weights thus generated is devoid of inconsistencies and the consistency thus achieved in this case is more than that of tolerance limits reported [23] in the literature of the Analytic Hierarchy Process.

3.5 Deduction of weights through fuzzy partial ordering

The weights of environmental issues is derived using the fuzzy partial ordering technique[3]. The fuzzy numbers in the relative weights matrix are transformed into crisp form by taking a central value of the diad. The fuzzy partial ordering technique is resolved into a series of crisp partial orderings by taking a series of a-cuts that produce increasing levels of refinement of rankings and value of a is varied from 0 to 1 [22]. Also, the ranking of environmental issues is obtained for different economic sections of the society.

The societal weights thus obtained can be used for a weighted aggregation of effect scores corresponding to environmental impact categories. The effect scores of environmental impact categories can be calculated using emission inventories following the procedure outlined by SETAC using equivalency factors.

4 Societal Ranking in National Capital Region

The salient environmental issues in the NCR are identified by referring to various environmental related documents viz. environmental status reports, carrying capacity study of the region, content analysis of national and federal environmental policy documents, statements of opinion makers / public participation records. The identified eleven environmental issues in the region are listed below:

[1] For details, refer to Appendix A.
[2] A brief description of the neural network is given in Appendix B.
[3] A brief description on fuzzy partial ordering technique is given in the Appendix C.

- *Local environmental problems:*
  - Air pollution
  - Water resource contamination
  - Noise
  - Odour
  - Solid waste disposal
- *Regional Level Problems*
  - Deforestation
  - Salinisation of soils
  - Soil erosion
  - Nutrification
  - Acidification
- *Global Level Problem*
  - Global warming

In the present study, the weighting of environmental issues by a representative group of different economic classes viz. higher income, middle income and lower income groups are elicited. The survey is conducted in all the sub-regions of the National Capital Region in India. As the focus of the study is on the development of societal ranking methodology, the number of respondents is limited only to forty individuals each from three economic groups. For an evaluation of environmental issues, the respondents are provided knowledge on the following aspects:

- current magnitude of the problem
- expected magnitude of the problem
- the difficulty in controlling the problem
- significance of the problem in most extreme situation
- the consequences of the problem.

The respondents are asked to compare environmental issues under multiple criteria such as effect on health, vegetation, and material or property; and discomfort due to pollution. The respondents were also provided with adequate information in the form of a dissemination package on "Carrying Capacity Based Developmental Planning in National Capital Region" carried out in this region [24].

The questionnaire contained 20 questions for comparing eleven environmental issues at different levels viz. local, regional and global. If the relative weights amongst local, regional and global level issues are not consistent with the directly elicited relative weights of components of local, regional and global issues, then it is assumed that the comparisons of the respondent are inconsistent, and hence discarded. Such responses were on the order of 20 percent of the total number of respondents. The relative ranking of the respondents are obtained in the linguistic form through a questionnaire. Each question compares two environmental issues in the context of the National Capital Region. The respondents are given five options as below:

a) Issue (1) is ***very serious*** as compared to issue (2)
b) Issue (1) is ***serious*** as compared to issue (2)
c) Both issues are of ***similar*** magnitude
d) Issue (2) is ***very serious*** as compared to issue (1)
e) Issue (2) is ***serious*** as compared to the (1)

The questionnaire is designed to form a maximum number of chained links viz. relative ranking of environmental issues ab, bc, ac; cd, ad, bd. Such chained transitive links are used to identify the logical connection operator. As indicated, the crisp neural network with three hidden neurons is found to be effective in identifying the logical connection operator and the neural network is subsequently used to delineate the matrix of relative weights. The inconsistency in this case is substantially lower than that of investigations in the literature using crisp representation for elicited relative ranking and multiplication as the logical connection operator. The matrix of relative weights in terms of fuzzy numbers is constituted in **Table 1** for the low income group. Similar matrices were also constituted for middle and higher income groups. The weights of environmental issues are finally derived through the fuzzy partial ordering technique involving a-cuts and a series of crisp partial orderings that produce increasing levels of refinement [22]. The normalised matrices of relative weights are delineated in (*Table* 2 through *4*), the row average of which gives the relative weight of an environmental issue.

The final results obtained through the five-step analysis of elicited relative rankings are delineated for different economic classes in **Table 5**. The lower income and middle income groups have rated issues related to water (water resource contamination and nutrification) as their major concern. This is because these sections reside in the outskirts of towns, cities and rural areas of NCR where water sources are increasingly under pressure. In addition, the lower and middle class localities in towns and cities are poorly serviced by water supply and sewerage systems. One unexpected finding is that the lower income group has ranked global warming as the third most important problem. This may be attributed to the fact that this section of society perceives that the global warming is caused by the greed of the elite sections of society and as a result of which vulnerable sections are the sufferers. The weighting of environmental issues, viz. air pollution as the important problem by higher income group, is as expected. This is because they generally reside in the heart of cities and towns, where the air pollution is critical due to traffic congestion and vehicular emissions. This is especially true in the case of Delhi and its surrounding industrial and commercial towns. Soil erosion and nutrification are second important problems in their priority list. This is logical, as the higher income group of NCR includes rich farmers and owners of farmhouses and fields in the outskirts of major urban centres. Also the nutrification of water bodies in this region has degraded many recreational sites.

The results of societal weighting in terms of relative weights are different for different customer/stake-holder groups and regions. These weights can be used to evaluate the satisfaction levels of different customer groups achieved due to product and process design choices in LCA.

5 Conclusions

The following are the salient conclusions that accrue from this study regarding the methodology of weighting of life cycle impacts through societal approach:

- The societal weighting methodology, through analysis of stated relative weights of environmental issues, has many positive features in comparison to that of methods using monetary valuation, sustainability levels, and modelling of eventual effects. The proposed method uses:

- triangular fuzzy numbers for representing non-specificities involved in elicited linguistic relative weights statements
- neural networks for identification of logical connection operator and delineation of matrix of relative weights
- fuzzy partial ordering to obtain weights of environmental issues using the matrix of relative weights
- This procedure minimises the inconsistencies in elicited relative weights in comparison to other elicitation procedures using Saaty's interval scale [23]
- The study also confirms that the perceptual ranking of environmental issues is different by different sections of the society.

The relative weights thus obtained can be effectively used in evaluation of life cycle impacts. Obviously, this method of weighting is effective in taking into account regional specificities as also preferences and expectations of different stakeholder groups.

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Table 1: Fuzzy matrix of relative weights for environmental issues elicited from low income group in the national capital region

	1	2	3	4	5	6	7	8	9	10	11
1	.25, .75	.23, .28	.19, .43	.13, .52	.09, .3	.13, .5	.12, .53	.13, .5	.1, .35	.14, .57	.15, .63
2	.72, .77	.25, .75	.31, .58	.18, .62	.13, .52	.15, .65	.17, .68	.16, .67	.14, .62	.17, .69	.21, .73
3	.57, .81	.42, .59	.25, .75	.38, .69	.18, .66	.21, .73	.23, .75	.21, .73	.17, .69	.23, .75	.31, .80
4	.48, .83	.37, .82	.31, .62	.25, .75	.29, .59	.23, .73	.25, .75	.23, .73	.23, .73	.25, .76	.29, .78
5	.7, .91	.48, .87	.34, .82	.41, .71	.25, .75	.48, .73	.42, .83	.47, .74	.29, .76	.55, .72	.54, .87
6	.5, .87	.35, .85	.27, .79	.27, .77	.27, .52	.25, .75	.38, .75	.19, .69	.3, .66	.23, .74	.28, .77
7	.47, .88	.37, .82	.25, .73	.25, .75	.17, .58	.25, .62	.25, .75	.45, .61	.23, .72	.2, .72	.28, .77
8	.5, .87	.33, .84	.27, .79	.27, .77	.26, .53	.31, .81	.39, .55	.25, .75	.15, .63	.21, .72	.24, .76
9	.65, .9	.38, .86	.31, .83	.27, .77	.24, .71	.34, .7	.28, .77	.37, .85	.25, .75	.3, .79	.42, .84
10	.43, .86	.31, .83	.25, .77	.24 .75	.28, .45	.26, .77	.28, .80	.28, .79	.23, .73	.25, .75	.5, .69
11	.37, .85	.27, .79	.20, .69	.22, .71	.13, .46	.23, .72	.28, .80	.24, .76	.16, .58	.31, .50	.25, .75

Environmental Issues
Noise; 2. Odour; 3. Solid waste disposal; 4. Air pollution; 5. Water resource contamination; 6. Salinity; 7. Soil erosion; 8. Deforestation; 9. Nutrification; 10. Global warming; 11. Acidification

Table 2: Matrix of relative weights showing the relative weights of low income group

	1	2	3	4	5	6	7	8	9	10	11	Row average
1	0.07	0.04	0.06	0.06	0.05	0.06	0.06	0.06	0.05	0.07	0.06	0.06
2	0.10	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.082
3	0.09	0.085	0.09	0.10	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.09
4	0.09	0.10	0.09	0.09	0.11	0.09	0.092	0.09	0.10	0.10	0.09	0.095
5	0.11	0.097	0.11	0.104	0.12	0.11	0.11	0.11	0.11	0.12	0.12	0.11
6	0.09	0.10	0.10	0.10	0.10	0.10	0.10	0.08	0.10	0.09	0.09	0.095
7	0.09	0.10	0.09	0.09	0.09	0.08	0.09	0.10	0.10	0.09	0.09	0.092
8	0.09	0.10	0.10	0.10	0.10	0.11	0.09	0.09	0.08	0.09	0.08	0.094
9	0.104	0.104	0.106	0.10	0.11	0.10	0.10	0.11	0.11	0.10	0.11	0.105
10	0.087	0.096	0.095	0.092	0.087	0.098	0.10	0.10	0.10	0.10	0.10	0.096
11	0.082	0.089	0.083	0.082	0.07	0.09	0.09	0.09	0.08	0.08	0.08	0.083

Environmental Issues
1. Noise; 2. Odour; 3. Solid waste disposal; 4. Air pollution; 5. Water resource contamination; 6. Salinity; 7. Soil erosion; 8. Deforestation; 9. Nutrification; 10. Global warming; 11. Acidification

Table 3: Matrix of relative weights showing the relative weights of middle income group

	1	2	3	4	5	6	7	8	9	10	11	Row average
1	0.087	0.096	0.085	0.082	0.089	0.084	0.090	0.084	0.092	0.080	0.080	0.086
2	0.095	0.106	0.103	0.105	0.110	0.133	0.110	0.100	0.100	0.100	0.077	0.1035
3	0.086	0.080	0.083	0.090	0.084	0.072	0.090	0.080	0.085	0.077	0.079	0.082
4	0.084	0.072	0.071	0.080	0.086	0.075	0.090	0.075	0.068	0.078	0.080	0.078
5	0.105	0.106	0.105	0.103	0.110	0.106	0.120	0.110	0.110	0.110	0.110	0.109
6	0.100	0.068	0.105	0.100	0.100	0.100	0.125	0.086	0.113	0.090	0.091	0.098
7	0.080	0.070	0.08	0.076	0.063	0.060	0.087	0.078	0.057	0.125	0..140	0.0718
8	0.102	0.106	0.100	0.100	0.100	0.110	0.105	0.100	0.087	0.091	0.093	0.099
9	0.105	0.120	0.105	0.110	0.120	0.100	0.130	0.130	0.120	0.095	0.097	0.112
10	0.068	0.066	0.080	0.072	0.060	0.070	0.020	0.0730	0.076	0.072	0.071	0.066
11	0.087	0.110	0.085	0.080	0.073	0.087	0.025	0.087	0.095	0.081	0.082	0.081

Environmental Issues
1. Noise; 2. Odour; 3. Solid waste disposal; 4. Air pollution; 5. Water resource contamination; 6. Salinity; 7. Soil erosion; 8. Deforestation; 9. Nutrification; 10. Global warming; 11. Acidification

Table 4: Matrix of relative weights showing the relative weights of high income group

	1	2	3	4	5	6	7	8	9	10	11	Row average
1	0.100	0.103	0.104	0.107	0.102	0.093	0.094	0.096	0.097	0.102	0.098	0.0996
2	0.085	0.088	0.100	0.097	0.094	0.088	0.100	0.077	0.090	0.075	0.092	0.0896
3	0.083	0.076	0.088	0.097	0.092	0.086	0.086	0.089	0.089	0.089	0.0897	0.0877
4	0.103	0.098	0.098	0.110	0.115	0.107	0.108	0.107	0.105	0.110	0.105	0.1060
5	0.100	0.094	0.095	0.093	0.100	0.103	0.097	0.104	0.100	0.107	0.100	0.0994
6	0.094	0.088	0.089	0.084	0.082	0.087	0.093	0.086	0.094	0.080	0.080	0.0870
7	0.110	0.100	0.100	0.103	0.105	0.095	0.102	0.082	0.120	0.103	0.100	0.1020
8	0.100	0.108	0.097	0.100	0.094	0.098	0.120	0.100	0.080	0.090	0.091	0.0980
9	0.110	0.100	0.100	0.107	0.105	0.095	0.088	0.121	0.105	0.103	0.100	0.1030
10	0.076	0.096	0.079	0.067	0.069	0.089	0.075	0.088	0.080	0.081	0.084	0.0803
11	0.042	0.046	0.048	0.034	0.038	0.061	0.0397	0.052	0.040	0.053	0.062	0.0468

Environmental Issues
1. Noise; 2. Odour; 3. Solid waste disposal; 4. Air pollution; 5. Water resource contamination; 6. Salinity; 7. Soil erosion; 8. Deforestation; 9. Nutrification; 10. Global warming; 11. Acidification

Table 5: Elicited ranking of environmental issues based on environmental score by low, middle, and higher income groups in the national capital region

Rank	Low Income Group	Middle Income Group	Higher Income Group
1	Water Resource Contamination (0.110)	Nutrification (0.112)	Air Pollution (0.106)
2	Nutrification (0.105)	Water Resource Contamination (0.109)	Soil Erosion and Nutrification (0.102)
3	Global Warming (0.096)	Odour and (0.104)	Noise and Water Resource Contamination (0.0994)
4	Salinity (0.095) Air Pollution (0.095)	Deforestation (0.995)	Deforestation (0.098)
5	Deforestation (0.094)	Salinity (0.098)	Odour (0.0896)
6	Soil Erosion (0.092)	Noise (0.086)	Solid Waste Disposal and Salinity (0.087)
7	Solid Waste Disposal (0.090)	Solid Waste Disposal (0.082)	Global Warming (0.080)
8	Acidification (0.083)	Acidification (0.081)	Acidification (0.047)
9	Odour (0.082)	Air Pollution (0.078)	
10	Noise (0.060)	Soil Erosion (0.072)	
11		Global Warming (0.066)	

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Appendix

Appendix A: Triangular Fuzzy Numbers (TFNs)

The salient features of fuzzy numbers are listed herein (KAUFMANN and GUPTA, 1988). Triangular fuzzy numbers are extensively used in the literature for representation of linguistic responses. Triangular fuzzy numbers are defined as a triplet (a_1, a_2, a_3) within an interval of confidence and have a membership function defined by four parameters:

$\mu A(x)$ is a membership function for the element x with respect to the fuzzy subset A.

$\mu A(x) =$ 0 when $x < a_1$
$\mu A(x) =$ $x - a_1 / a_2 - a_1$ when $a_1 <= x <= a_2$
$\mu A(x) =$ $a_3 - x / a_3 - a_2$ when $a_2 <= x <= a_3$
$\mu A(x) =$ 0 when $x > a_3$

The interval of confidence represents differing levels of certainty, another often used term is possibility. The interval of confidence at level a is:

$$A = [(a_2 - a_1)\alpha + a_1, - [(a_3 - a_2)\alpha + a_3]$$

The interval of confidence at alpha level designates the amount of membership along either the increasing or decreasing slopes in the figure above for $\alpha = 1$, then the membership function is the maximum and for $\alpha = 0$, the membership function is minimum.

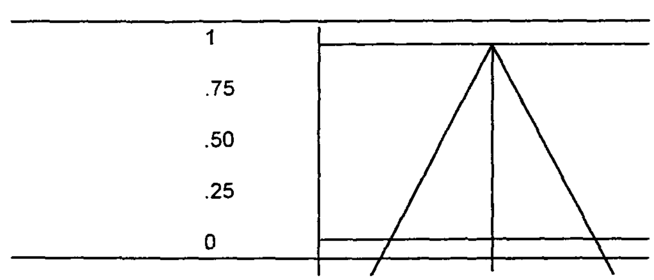

Fig. A: A Triangular Fuzzy Number (TFN) A = (a_1, a_2, a_3)

Appendix B: Back-Propagation Algorithm – Crisp Neural Network

A multilayered feed-forward crisp neural network consists of three layers of neurons, viz. the input, the hidden, and the output. Back-propagation algorithm used for training the neural network follows the procedure of repetitively presenting a set of input patterns and corresponding target patterns; and iteratively adjusting the values of the connection weights so as to minimize the average squared output deviation error function over all training patterns.

The simplest multilayered feed-forward neural network consists of three layers of neurons, viz. the input, the hidden, and the output with n_i, n_h and n_o neurons, respectively. The input pattern, which is a vector of real elements of dimension n_i, is fanned out by the input neurons, processed, and forwarded to the output layer through the hidden layer weighted by the connection strengths from all the nodes (sending neurons) of the preceding layer. Processing nodes in the hidden or output layers collect the sum of the output values from the preceding layer, activate it through a sigmoidal function, and forward the resultant outputs to all the connections towards the nodes of the successive layers. The number of neurons in the input and output layers are determined by the system description. There are no generic rules for the choice of the number of neurons in the hidden layers. The values of the connection weights are determined in an interactive manner through a training procedure.

Appendix C: Fuzzy Partial Ordering Technique

When a fuzzy partial ordering is defined on a set X, then two fuzzy sets are associated with each of elements x in X. The first is called the dominating class of x. It is denoted by $R_{\geq [x]}$ and is defined by

$$m_{R\geq [x]}(y) = \mu R(x, y),$$

where $y \in Y$. In other words, the dominating class of x contains the members of X to the degree to which they dominate x. The second set of fuzzy set of concern is the class dominated by x, which is denoted by

$$R_{\leq [x]}(y) = \mu R(x, y).$$

Where y is dominated, class x contains the elements of X to the degree to which they are dominated by x.

An element $x \in X$ is undominated if and only if

$$\mu R(x, y) = 0$$

for all $y \in X$ and $x \neq y$; an element x is undominating if and only if

$$\mu R(y, x) = 0$$

for all $y \in X$ and $y \neq x$.

Institutions: The LCA-Society of Italy

Gian Luca Baldo[1], Antonio Giacomucci[2]

[1] Independent LCA Peer Reviewer; Via Val Lagarina, 54, I-10142 Torino, Italy
[2] ABB Ricerca S.p.A., Viale Edison, 50, I- 20099 Sesto San Giovanni (MI), Italy

The Italian Society of LCA ("Associazione Italiana di Analisi del Ciclo di Vita") was officially established in March 1999 at the Environment Park of Turin.

After about two years of meetings, and an exchange of information and ideas via e-mail, the legal form of the association and its location were finally agreed upon.

Environment Park is a Science and Technology Park dedicated to environmental technologies. Since Environment Park has the primary purpose of promoting the development of applied environmental research and facilitating the integration of environmental variables and factors into the process of production, as well as bringing the world's researchers and businesses together, the unification with the Italian Society of LCA seemed to be a good opportunity both for the site and the common objectives.

With over 50 members representing the most important industries (ABB, ENI, FIAT, ITALTEL, PIRELLI, TELECOM), universities (Bari, Bologna, Torino, Palermo), research centres (ENEA, Fiat Research Centre), environmental agencies (national and local EPAs) and consulting companies (Boustead, Ecobilan, Take Care), it is now the most important referrence point for LCA activities in Italy.

The promotion of LCA development, as well as the review of proposed legislation and environmental standards with LCA implications, is the primary mandate of the association. Several operative actions, such as the definition of discussion panels (e.g. on Life Cycle Impact Assessment, Life Cycle Costing, Energy systems, ...), organisation of seminars and internal working groups, are ongoing. Furthermore, according to EPA indications, the possibility to create an internal board for critically reviewing LCA public works in Italy is also being considered.

Environment Park (Turin) and ENEA (Bologna) will house two open libraries containing papers and books, while a web site will ensure up to date information about news and events. The growing presence of students working in this field in Italy now has the possibility of looking for information in a few places and of receiving assistance from LCA practitioners via e-mail.

Some members are present on international boards such as SETAC's Steering Committee and the ISO working groups for the 14.040 series.

For more information, please contact:
Alexandra Robasto
Environment Park SpA
Via Livorno 60 - 10144 Torino
Ph. +39 011 22 57 111 Fax. +39 011 22 57 221
e.mail: arobasto@envipark.com
URL: www.envipark.com